Virtual reality training improves accommodative facility and accommodative range

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# Abstract

Background

To evaluate the effects of virtual reality (VR) training on different parameters of vision.

Methods

Individuals with healthy eyes admitted to the First Affiliated Hospital of Zhejiang University or Shulan Hospital from November 2018 to June 2019 were randomly divided into short-term (n = 40) and long-term (n = 20) treatment groups. They were given a specially designed VR training device only once for 15 minutes or 3–4 times a day for 15 minutes each time for one month. The visual acuity, spherical equivalent, accommodative range, accommodative facility, pupil size, and visual fatigue were evaluated before (control) and after VR training.

Results

The visual acuity, accommodative range, and accommodative facility increased in subjects of the short-term treatment group, whereas the pupil size contracted significantly. No significant changes in spherical equivalent and visual fatigue were observed. The changes in distant vision and corrected visual acuity were positively correlated with those in pupil size, but not with spherical equivalent. The accommodative range and accommodative facility improved significantly in subjects of the long-term treatment group. No significant changes in visual acuity, spherical equivalent, pupil size, and visual fatigue were noted.

Conclusions

VR training can improve the accommodative range and accommodative facility of human eyes. Although short-term VR training can transiently improve vision, which was probably due to bright light adaptation, there is no evidence that it can improve myopia.

Trial registration:

Retrospective registration ChiCTR2000029793. Date of Registration: 2020-02-14.

Background

Virtual reality (VR) refers to the user's interactive experience with the virtual three-dimensional (3D) world through head-mounted displays and wearable devices. The technology has been widely used in the fields of education, entertainment, medicine, industrial engineering, and commerce, as well as various civil fields. [1,2]

In China, more than 600 million people have myopia, with an epidemiological survey indicating that approximately 80% of primary and secondary school students suffer from the condition. [3] Therefore, devices that can control or prevent myopia are likely to have a broad market in China. Several investigators have reported that VR devices can ideally simulate outdoor light, [4] train the ciliary muscle, relieve ciliary spasms to release visual fatigue, [5] and slow-down the development of myopia. Furthermore, Shibata et al. revealed that visual acuity increased after viewing stereoscopic 3D images on developed displays, [6] which subsequently prompted Zhao et al. to hypothesize that specially designed VR devices may help to prevent myopia. [7] However, many studies have reported inconsistencies between accommodation and convergence when viewing 3D videos, which may be due to functional eye conditions such as visual fatigue, dry eyes, transient accommodative strabismus, and video terminal syndrome. [8,9] Interestingly, Suh et al. reported that watching 3D videos can lead to transient myopia. [10] Presently, the effects of VR device use on vision are not clear, and it is unknown whether a specially designed VR training device can eliminate visual fatigue and improve myopia.

The aim of this study was to evaluate the visual acuity, diopter, pupil size, accommodative range, accommodative facility, and visual fatigue symptoms, as well as correlations between these parameters, before and after use of a VR training device specially designed for accommodation training. We also determined the effects of the VR training device on accommodation and convergence.

Methods

Criteria of enrolled patients

Subjects 18 to 60 years old admitted to the First Affiliated Hospital of Zhejiang University or Shulan Hospital from November 2018 to July 2019 who were willing to participate in this clinical trial were enrolled. The inclusion criteria were a corrected visual acuity in both eyes of > 0.8, binocular stereopsis, $-6.00D \le$ spherical equivalent $\le 6.00D$, $-3.00D \le$ astigmatism $\le +3.00D$, and no evidence of anisometropy. Subjects had no history of organic ophthalmic diseases, ophthalmic surgeries, and serious systemic diseases, and they had normal cognitive ability. The study protocol was approved by the University Research Ethics Committee, and this clinical trial has been registered in the Chinese Clinical Trial Registry (ChiCTR2000029793).

Parameters of VR training

The VR training device used in this study was produced by Hangzhou Look Technology Co., Ltd. The main body of the device was comprised of a VR headset and a mobile phone (Fig. 1). The VR headset lens was constructed of optical polymethyl methacrylate (PMMA) materials. The single field of view angle was 110° (55° for the half field of view), and the distance of the virtual image displayed on the mobile phone screen from the human eyes was 25 cm. The LeTV Max 2 mobile phone (1440 · 1280p) was used. The brightness of the mobile phone screen was set to automatic before the test.

The VR video was produced by Hangzhou Look Technology Co., Ltd. This device used "depth of field synchronization" and "focus follow-up" to produce videos and real-time binocular images, which simulated the subtle differences in the angle, path, and light intensity of the incident glasses in distant and nearby views. In the video, the subject moved back-and-forth and turned around. In the long-range view (i.e., infinity), the subject had an infinite convergence angle of 0°. In the short-range view, the convergence angle was 30°, which was approximately 11.6 cm away from the human eyes (calculated using a pupil distance of 62 mm, slightly different for individuals with different pupil distances). The subject was located in front of the eyes and turned around three times with a half viewing angle of 30°. The total length of the video was 15 minutes, and the frame rate was 60 frames per second. One cycle consisted of one forward and backward motion each at low speed, as well as one forward and backward motion each at high speed, with the subject turning around three times. One cycle lasted approximately 30 seconds (Fig. 2).

Treatment groups and methods

The short-term treatment group consisted of 40 randomly assigned subjects.

The subjects underwent six tests to determine naked distant vision, best corrected visual acuity, diopter (using the ARK-1S automatic computer optometer, which recorded the spherical equivalent), accommodative range (using the ARK-1S automatic computer optometer), and accommodative facility. The visual fatigue symptoms were recoded via a questionnaire on eye dryness, double vision, lacrimation, puffy eyes, photophobia, eye-strain, headache, dizziness, nausea, drowsiness, and difficulty concentrating. Each parameter was divided according to the degree of subjective feeling, and scores of 0 to 5 corresponded to "completely no”, “uncertain”, “a little”, “feeling”, “stronger feelings” and “very strong feelings”. The subjects wore the VR device for 15 minutes, during which time they gazed at the moving object in the video. The subject then closed their eyes and rested for 5 minutes. Lastly, the subjects underwent the six aforementioned tests.

The long-term treatment group consisted of 20 randomly assigned subjects.

The six baseline examinations were completed as in the first group. The subjects were asked to use the VR device 3–4 times a day for 15 minutes each time. The intervals between the training sessions were each longer than 2 hours. Individuals were asked to come to the hospital one month later (± 7 days) for six examinations. They were asked not to use the VR device and to come to the hospital on the same day that baseline measurements were collected.

All the tests were completed by professional technicians who were not involved in this research study.

Statistical methods

SPSS 22.0 Software was used for data analysis. For the six main observation indicators, the Kolmogorov–Smirnov test was used to determine whether the data was normally distributed. If the data conformed to a normal distribution, the results were presented as means ± standard deviation. If the data did not conform to a normal distribution, the results were presented as medians (P25–P75). If data did conform to a normal distribution, the paired sample t-test was used to compare the differences between before and after use. If data did not conform to a normal distribution, the Wilcoxon sign rank sum test of paired samples was used to compare the differences between before and after use. For visual acuity, diopter, and pupil size, in-pair correlation tests were used to test the correlation between the two groups. If data from both groups conformed to a normal distribution, the Pearson test was used. If data from one group did not conform to a normal distribution, the Spearman test was used. P-values < 0.05 were considered statistically significant.

Results

The distant vision and corrected visual acuity of subjects in the short-term treatment group improved significantly by -0.09 (95% CI, -0.12 – -0.06, $P < 0.001$) and – 0.04 (95% CI, -0.06 – -0.02, $P < 0.001$), respectively. In addition, the accommodative range and accommodative facility increased significantly by 0.41 (95% CI, 0.11–0.71, $P = 0.71$, $P = 0.008$) and 1.29 (95% CI, 0.95% CI, 0.84–1.74, $P < 0.001$), respectively. The pupil contracted significantly by -0.34 (95% CI, -0.46 – -0.22, $P < 0.001$). No changes were observed in spherical equivalent and visual fatigue (Table 1). There were positive correlations between the changes in distant vision (r = 0.361, $P < 0.01$) and corrected visual acuity (r = 0.516, $P < 0.01$) after the test and the changes in pupil size, indicating that the improvements in distant vision and corrected visual acuity were related to the pupil size but not to the spherical equivalent ($P > 0.05$) (Table 2).

Table 1
Changes in visual function after the use of the VR training device for 15 minutes

	Pre-test data (M ± SD)	**Post-test - pre-test M (95% CI)**	**P**
Distant vision (LogMAR)	0.46 ± 0.48	-0.09 (-0.12 – -0.06)	< 0.001
Corrected visual acuity (LogMAR)	-0.02 ± 0.11	-0.04 (-0.06 – -0.02)	< 0.001
Spherical equivalent (D)	-1.93 ± 2.17	0.05 (-0.04–0.13)	0.289
Accommodative range (D)	3.42 ± 2.60	0.41 (0.11–0.71)	0.008
Accommodative facility (/min)	12.60 ± 5.33	1.29 (0.84–1.74)	< 0.001
Pupil size (mm)	5.46 ± 0.65	-0.34 (-0.46–-0.22)	< 0.001
Visual fatigue	4.00(1.00–9.00)	1.90	P = 0.058

Table 2
Correlations between diopter, pupil size, distant vision, and corrected visual acuity

	Spherical equivalent	Pupil size
Distant vision	0.076	0.361#
Corrected visual acuity	0.063	0.516#
Note: # represents $P < 0.01$; Pearson correlation test was adopted.		

The accommodative range and accommodative facility of subjects in the long-term treatment group increased significantly by 0.69 (95% CI, 0.26–1.11, $P < 0.01$) and 0.90 (95% CI, 0.45–1.35, $P < 0.01$), respectively. No changes were observed in distant vision, corrected visual acuity, spherical equivalent, pupil size, and visual fatigue ($P > 0.05$) (Table 3).

Table 3
Changes in visual function after the use of the VR training device for 1 month

	Pre-test data (M ± SD)	The use after one month - before the test M (95% CI)	P
Distant vision (LogMAR)	0.55 ± 0.44	− 0.02 (-0.07-0.02)	0.248
Corrected visual acuity (LogMAR)	-0.05 ± 0.08	0.00 (-0.02-0.03)	0.734
Spherical equivalent (D)	-2.57 ± 2.20	− 0.08 (-0.17-0.02)	0.119
Accommodative range (D)	3.44 ± 2.50	0.69 (0.26–1.11)	0.002
Accommodative facility (/min)	12.05 ± 5.09	0.90 (0.45–1.35)	< 0.001
Pupil size (mm)	5.48 ± 0.68	− 0.16 (-0.33-0.01)	0.058
Visual fatigue	0.50(0.00-6.25)	-1.78	P = 0.058

Discussion

This study examined the changes in visual acuity, diopter, accommodative function, pupil size, and visual fatigue in subjects after use of a VR training device for just 15 minutes or one month, and it explored the correlations between these parameters. We found that naked distant vision and corrected visual acuity of subjects improved significantly after using the VR training device for 15 minutes compared with before use (control), which is consistent with the results of Shibata et al.[6] No significant change was found in the diopter, and there were no correlations between the spherical equivalent and visual changes, indicating that the improved visual acuity after the use of the VR training device was not related to changes in the diopter (i.e., pseudo myopia). However, there was a strong positive correlation between visual acuity and pupil size; the pupils of the subjects contracted significantly after using the VR device compared with before use, revealing that the improved naked distant visual acuity and corrected visual acuity were due to the contraction of the pupil size after using the device. Emoto et al. examined subjects who watched 3D television and reported significant pupil contraction after the test. They suggested that visual fatigue and accommodative spasms might have contributed to myosis. [11,12] However, we found that 15 minutes of use of the VR training device did not significantly increase visual fatigue, and the accommodative facility was significantly improved compared with before use, indicating that visual fatigue did not cause myosis. To determine the cause of myosis, an illuminometer was used to detect the brightness of the VR training device and test environment. An average of five consecutive measurements revealed an illumination of 272.4 lx for the test environment but 80.2 lx for the VR training device, which was similar to watching a VR video in a relatively dark room. These findings were also consistent with most individuals' subjective feelings of external illumination immediately after taking off the VR headset. Therefore, only subjects responsive to increased ambient brightness may have experienced myosis. This may have been due to the fact that VR headsets enclosed both eyes by the nature of their design, and the effect of watching a VR video was similar to that of watching a movie in a theatre. However, few studies have reported changes in diopter and pupil size, as well as the brightness of the device and environment; thus, it is not known whether VR devices can improve vision by training ciliary muscles and relaxing accommodative spasms.

After one month of continuous use of the VR device, there were no significant changes in naked distant vision, corrected visual acuity, diopter, pupil size, and visual fatigue. In a previous study involving individuals (32 subjects aged 20 ± 1 years and 12 subjects aged 46.6 ± 3.5 years) exposed to 6 minutes of use of a VR device for 11 consecutive days, it was found that the distant vision improved in both young and old groups after five days, with the myopic diopter decreasing in the young group. [5] However, the authors failed to provide the details of the VR device, the number of training sessions per day, and the specifics of other endpoints; therefore, it was difficult to conduct in-depth comparative analyses. According to our results, we supposed that the visual acuity measurements might have been taken just after VR training, and the improvement in distant vision was caused by light adaptation to myosis and had nothing to do with myopia relief.

Although various 3D displays have been produced based on the parallax principle, they associate with inconsistent accommodation and convergence because the display position remains unchanged. [13] Therefore, the actual impact of such devices on the accommodative function of subjects remains controversial. [14] In view of the changes in accommodative function, several studies have combined 3D displays with optometric instruments to measure the change in diopter when subjects are watching 3D films in real-time. Although the position of the actual display had not changed, the results showed that the diopter of the human eye accommodated to the distance of the virtual image, suggesting that VR training may indeed play a role in accommodation. [6,15] We found that the accommodative range and accommodative facility were significantly increased after using the VR device for 15 minutes, which is consistent with the results of Zhang et al., [16] as well as after one month of continuous use of the VR device. These findings indicate that the VR device can improve the eye's ability to accommodate the lens and can delay the development of presbyopia to a certain extent. It should be noted that VR training for more than 30 minutes significantly increased visual fatigue, whereas accommodative range and accommodative facility decreased.

The pathogenesis of myopia is complex. It is believed that a low degree of hyperopic defocus of the peripheral retina may be the key factor leading to myopia, [17] but the role of accommodative function in the development of myopia is unknown. [18] Screenivasan et al. examined 25 children with emmetropia and 27 children with myopia, and reported that poor accommodative facility and stability were risk factors for myopia. [19] We found that the accommodative facility of subjects after the use of the VR device was significantly higher than that before use. In theory, the use of the VR device may delay the development of myopia. However, we found that the unchanged diopter after VR training may have been related to the lack of children and insufficient follow-up time. Further studies are needed to confirm the effects of VR training on the development of myopia in juveniles.

This clinical trial is one of few studies that comprehensively evaluate the impact of VR training on vision and explore the relationship between various indicators. Unlike other studies, this trial introduced the parameters of the VR training device, which will aide in subsequent analyses. However, there were many limitations. Firstly, this trial did not include juveniles younger than 18 years of age due to ethical constraints. Given that ciliary muscle accommodation was improved in adults, and there were no cases of pseudomyopia and other disorders, the conclusion that VR training has no effect on the diopter of human eyes may not be applicable to juveniles. Secondly, the follow-up time was short due to time constraints. Further clinical trials with an observation time of not less than half a year are needed. Although this is the longest clinical study on the effects of VR training on vision, there is no reason for the lack of effects of VR training on diopter. Lastly, the population size was small and subgroup analysis could not be performed.

Conclusion

Specially designed VR training devices can improve the accommodative facility and accommodative range. Although short-term VR use can transiently improve visual acuity, this was possibly due to bright light adaptation. There is no evidence at the present time that VR training can improve myopia.

Abbreviations

VR: Virtual reality; 3D: Three-dimensional; PMMA: Polymethyl methacrylate; Co.,Ltd: Company limited; LogMAR: Logarithm of the minimum angle of resolution

Declarations

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of First Affiliated Hospital of Zhejiang University and this clinical trial has been registered in the Chinese Clinical Trial Registry (ChiCTR2000029793). All participants has signed informed consent prior to the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that there is no competing interest regarding the publication of this article.

Funding

None.

Authors' contributions

DG, YZ, XW, and JX conceived and designed the analysis. DG and YL were the major contributors in writing the manuscript. YG and YL revised the manuscript and contributed significantly in the discussion section. All authors have read and approved the manuscript.

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Figures

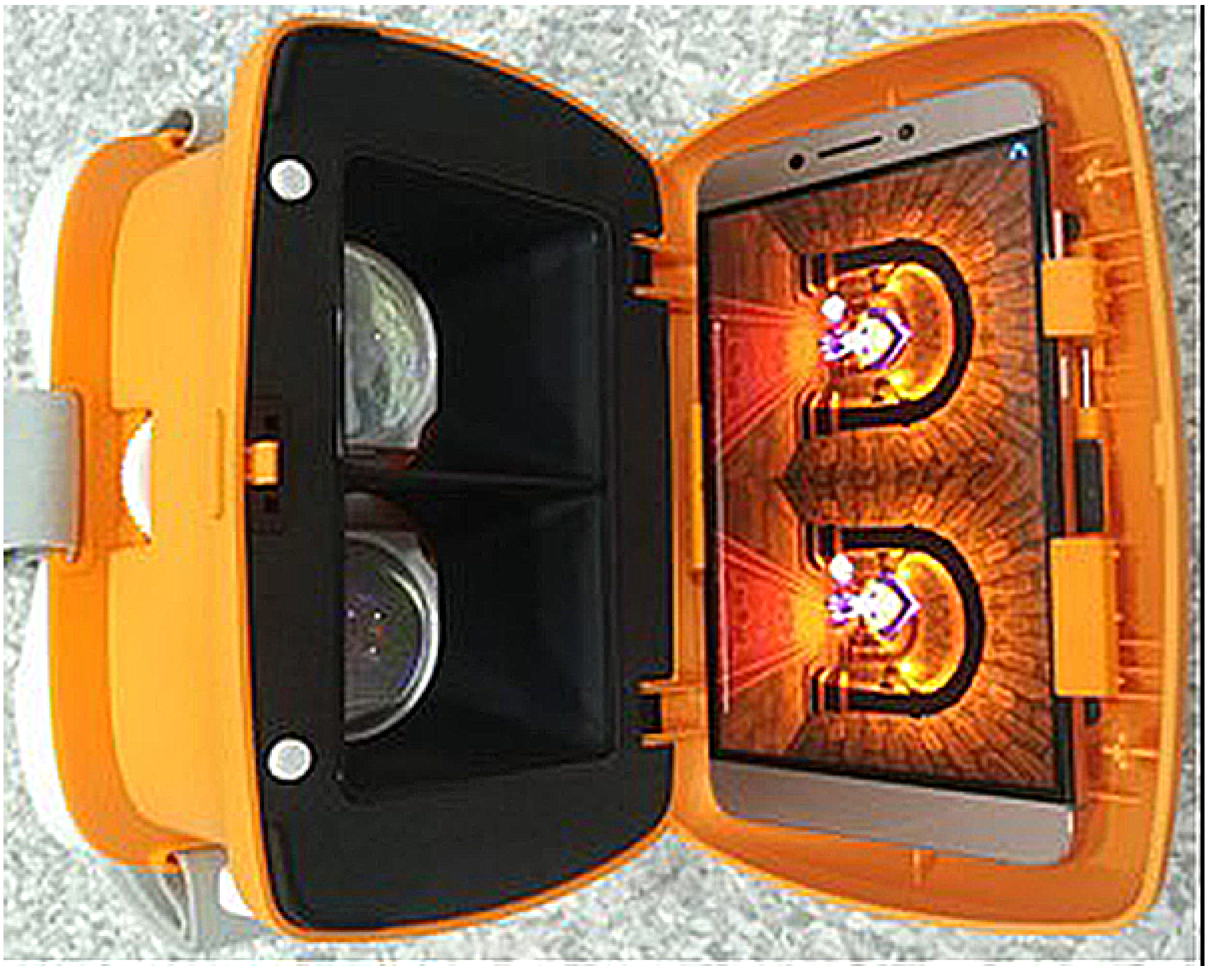

Figure 1

VR training device used in this clinical study.

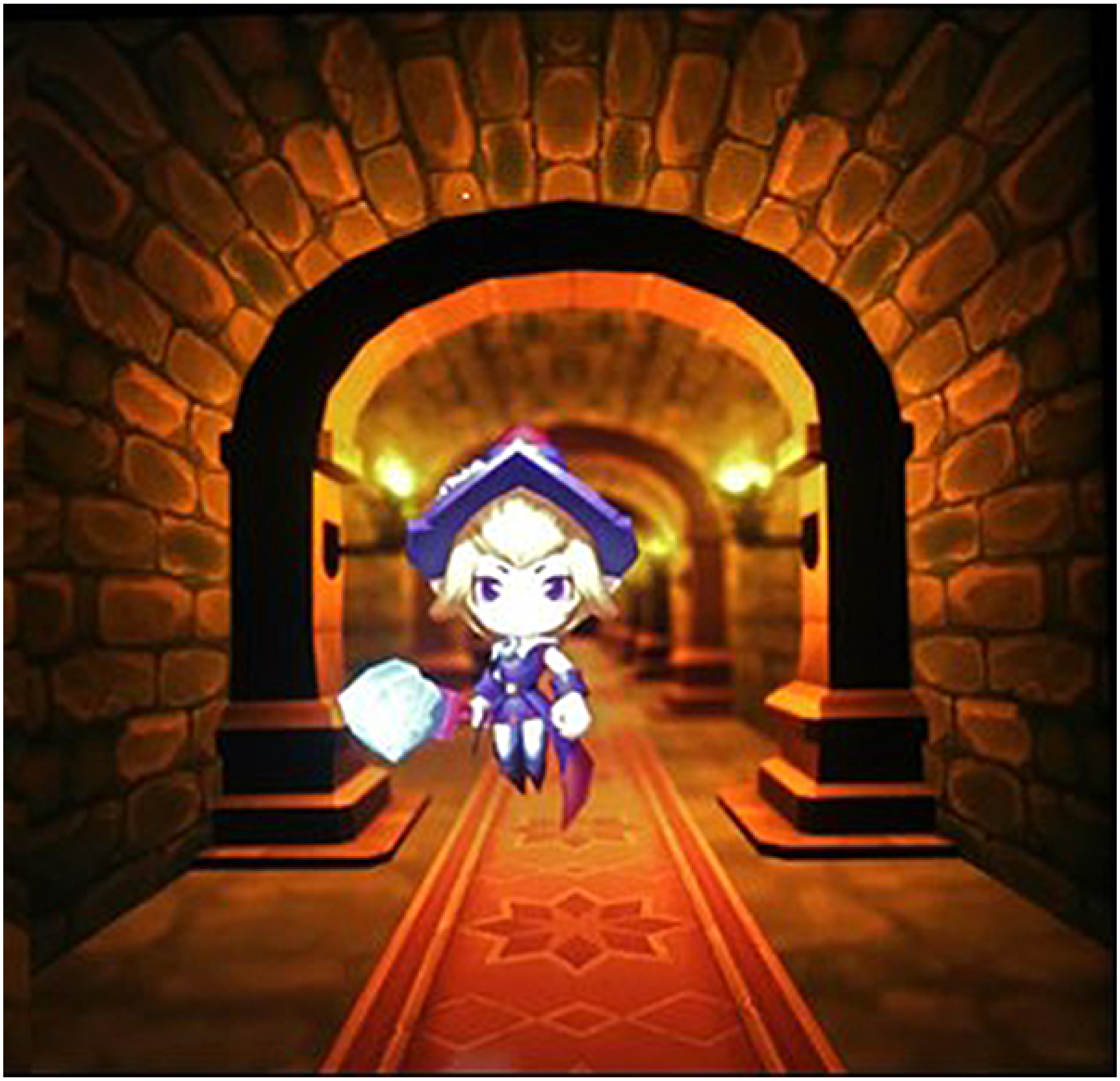

Figure 2

VR training video. In the video, the subject moved close and far, and then turned around. The submission of this manuscript for publication was authorized by Hangzhou Look Technology Co., Ltd.

Supplementary Files

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- CONSORT2010Checklist.doc